



Study of Small Colliding Systems

Li Yi

Shandong University

li.yi@sdu.edu.cn

Outline

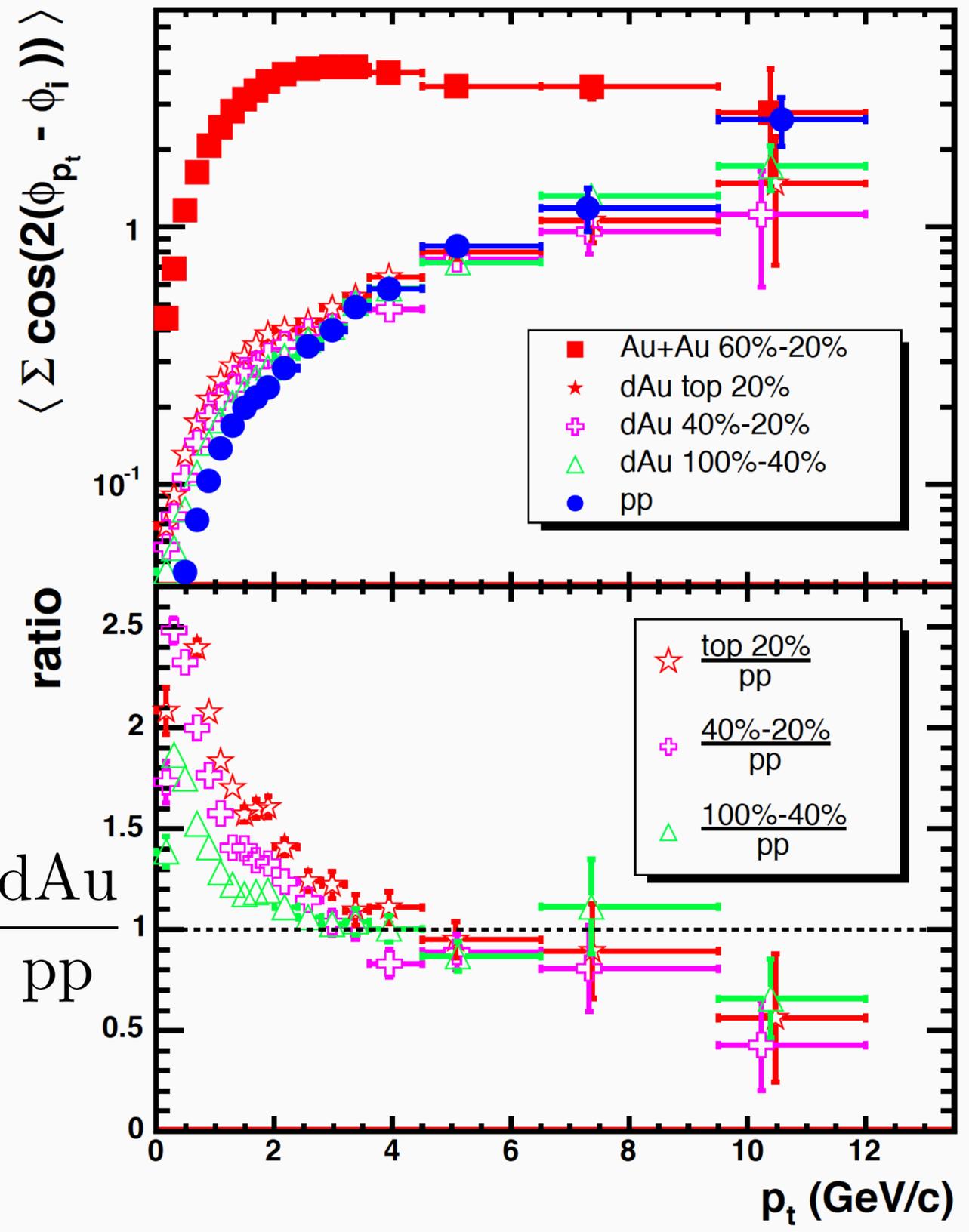
- A few selected small system results
- Collectivity in small systems
 - What have been observed?
 - Could models be falsified?
- Summary

Results on Small Systems

- Particle chemistry
- Jet and high- p_T
- Electromagnetic and weak probes
- **Collectivity**

d+Au Scalar Product at Early Years

STAR, PRC 72 014904 (2005)



dAu **finite** difference from pp at low p_T

Indication of flow in dAu?

Increasing with multiplicity, a different trend in AuAu

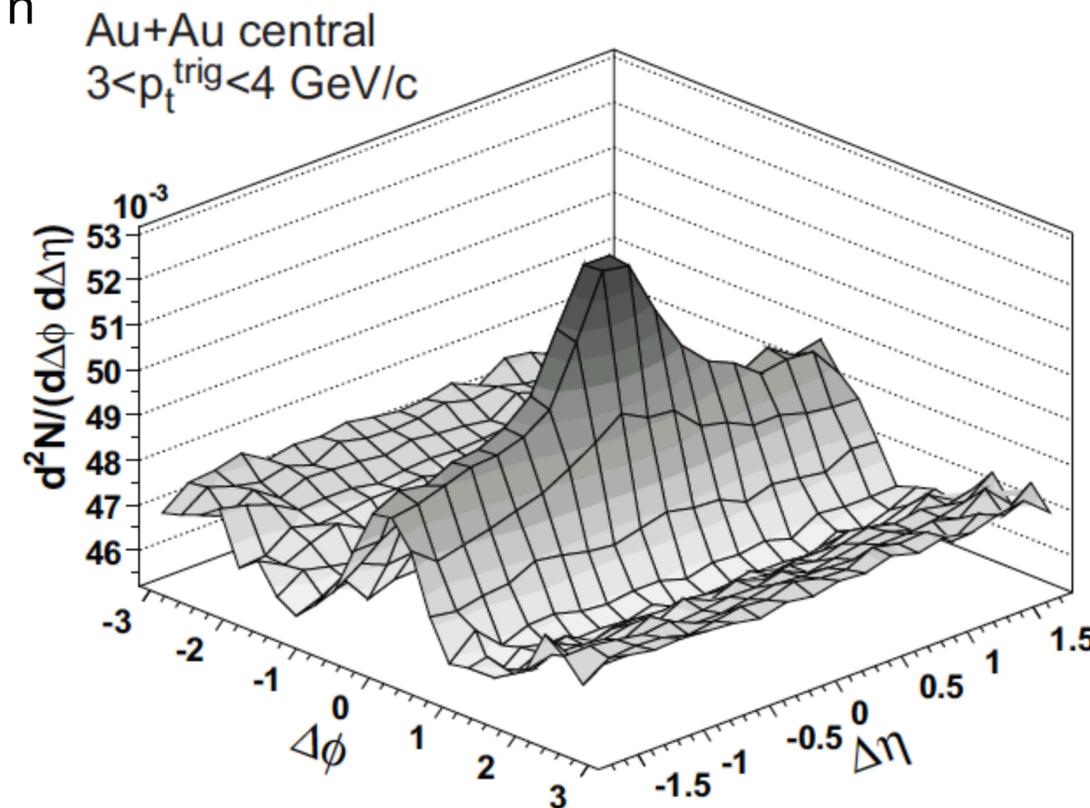
Hijing does not reproduce this

Ridge in HIC: Long-range Correlations

v_2 subtracted, higher order v_n

Alver, Roland, PRC81(2010)054905

STAR, PRC 80 (2009) 064912



Initial state geometry \rightarrow final state long-range correlations

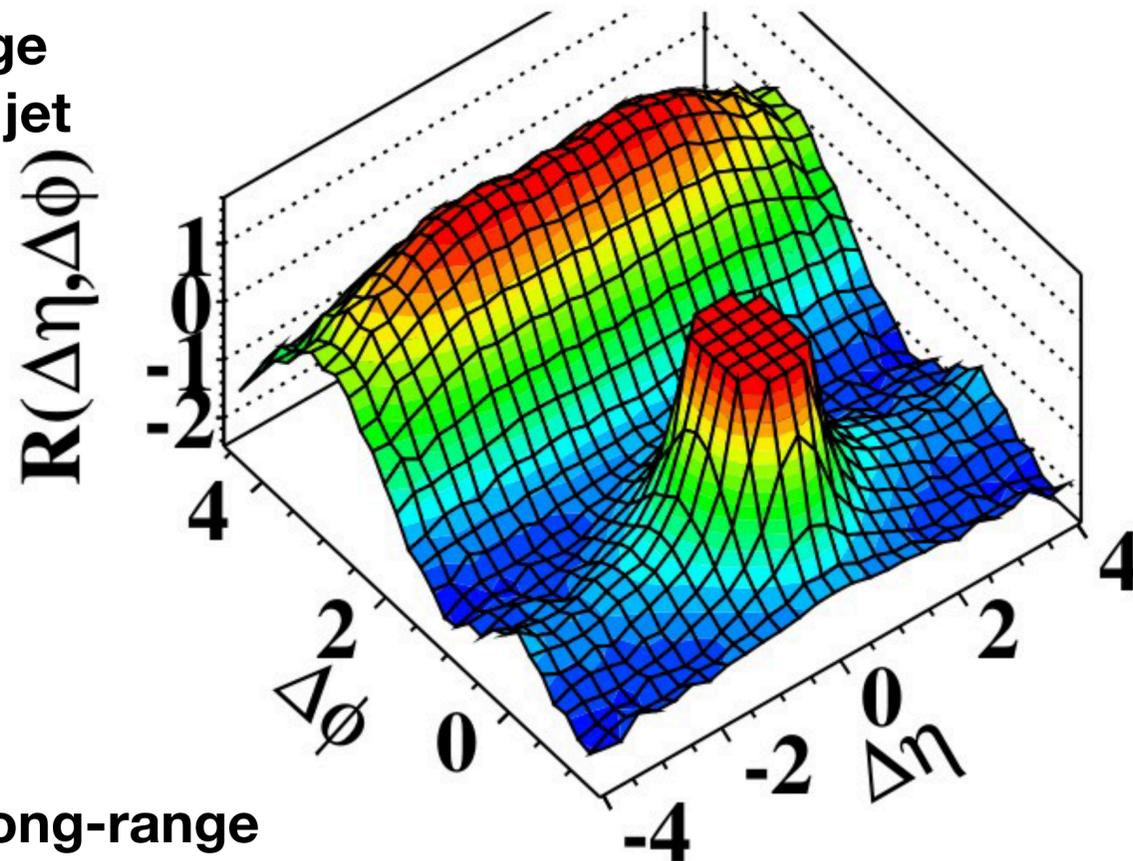
Nearly perfect fluid

Ridge in High Multiplicity pp

CMS, JHEP 09 (2010) 091

(d) CMS $N \geq 110$, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

Long-range
Away-side jet



Long-range
Ridge

Short-range
Near-side Jet

Collectivity in small systems

~ year 2005: sQGP signature

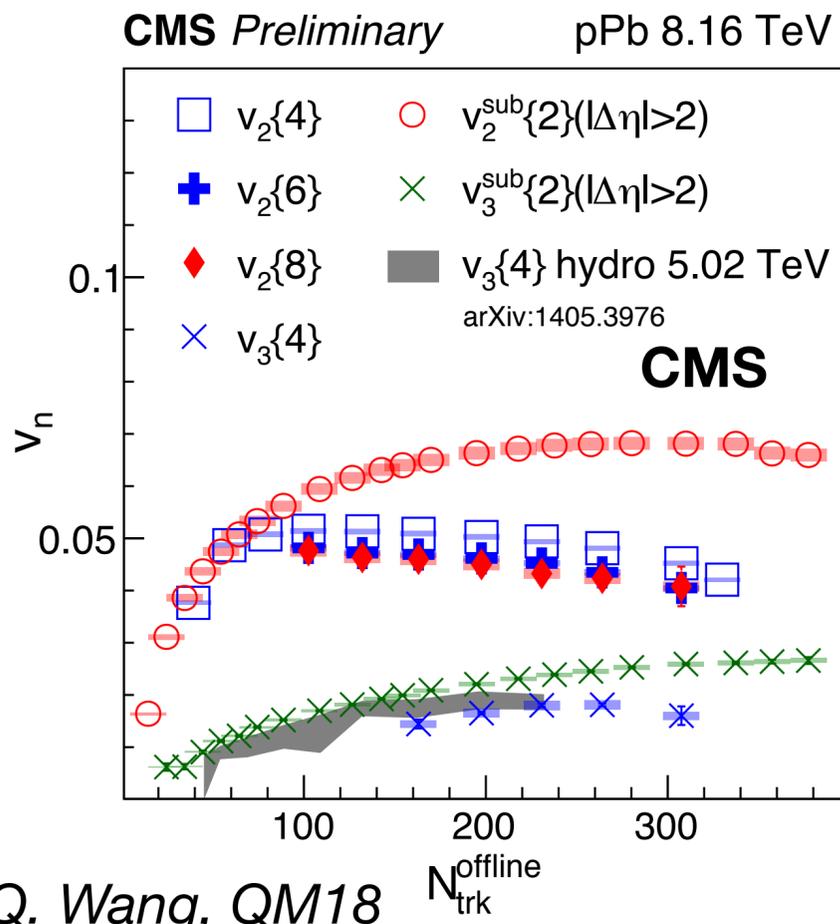
~ year 2010: sQGP in pp as well?

ridge includes v_2 + higher orders

Bounty Evidence of Collectivity at LHC

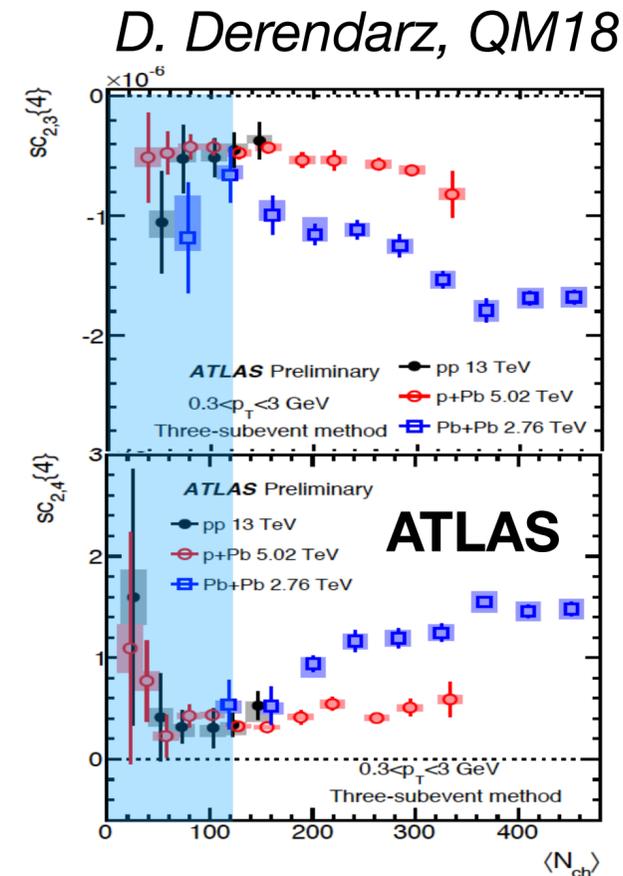
Selected few QM results

Multi-particle v_n



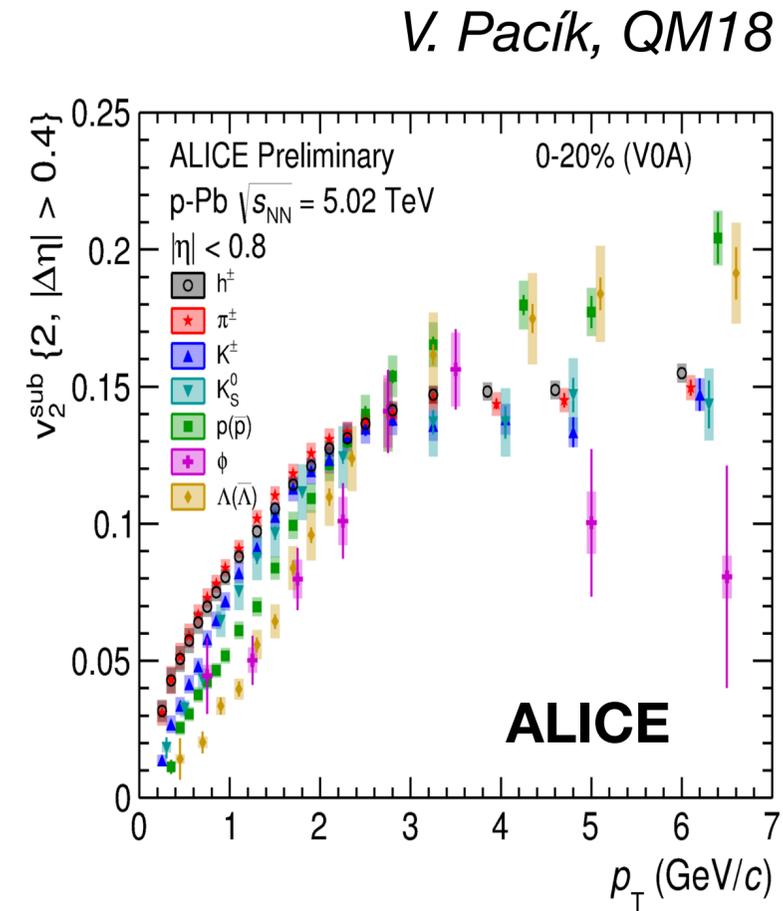
$v_3\{4\} \neq 0$

Sub-event cumulants



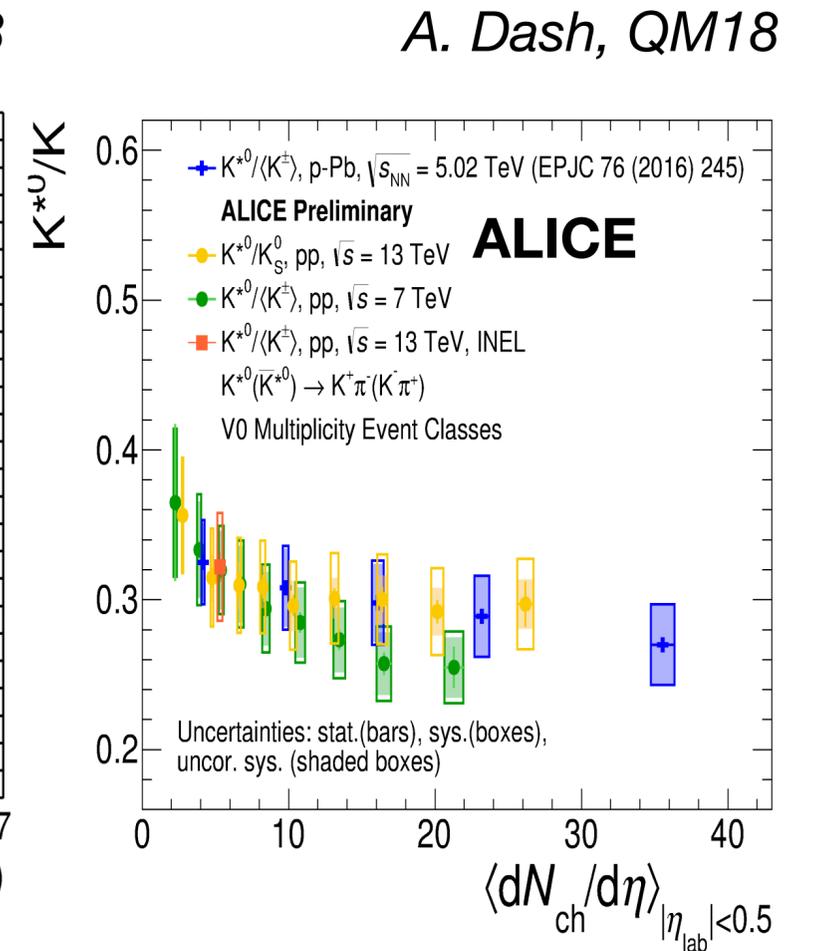
Overlap multiplicity range:
system independent

PID v_2



Mass ordering

Resonance

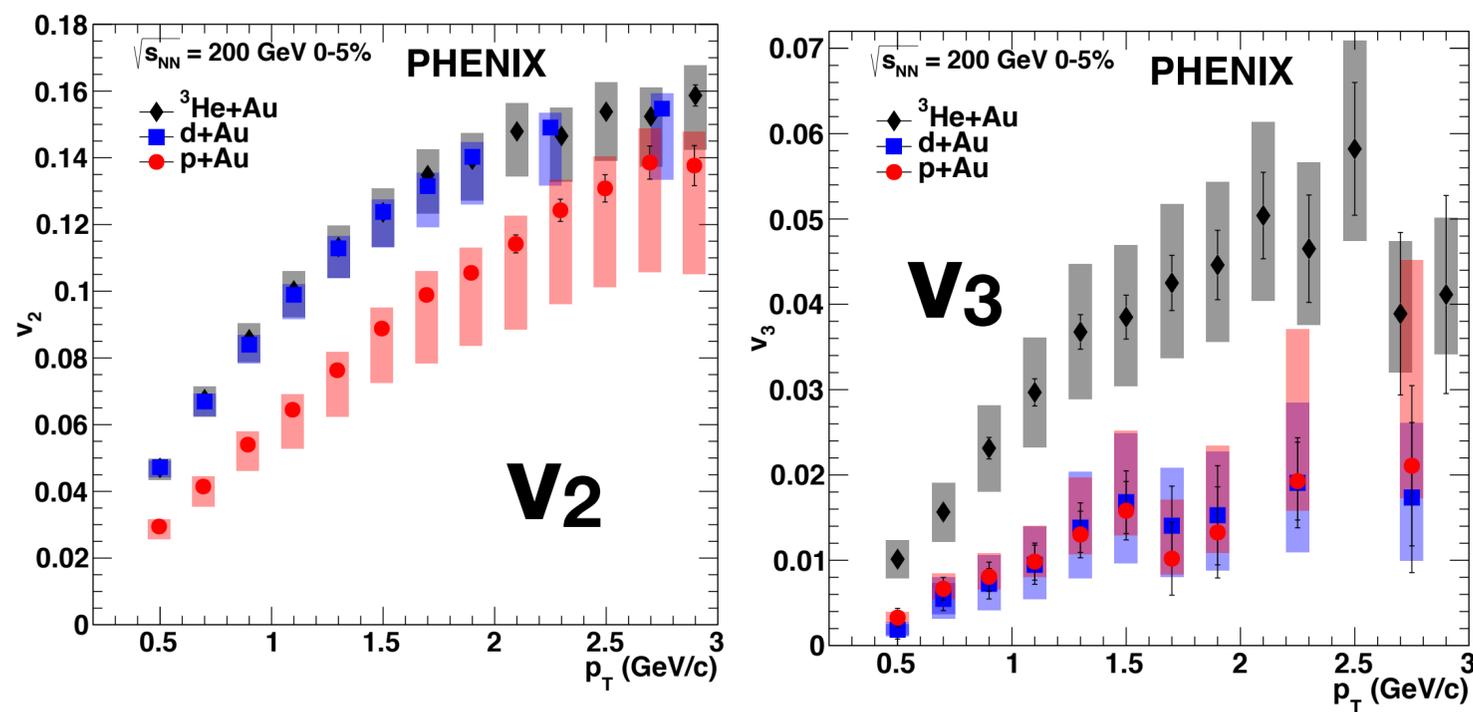


Re-scattering

Evidences of Collectivity at RHIC

Selected few QM results

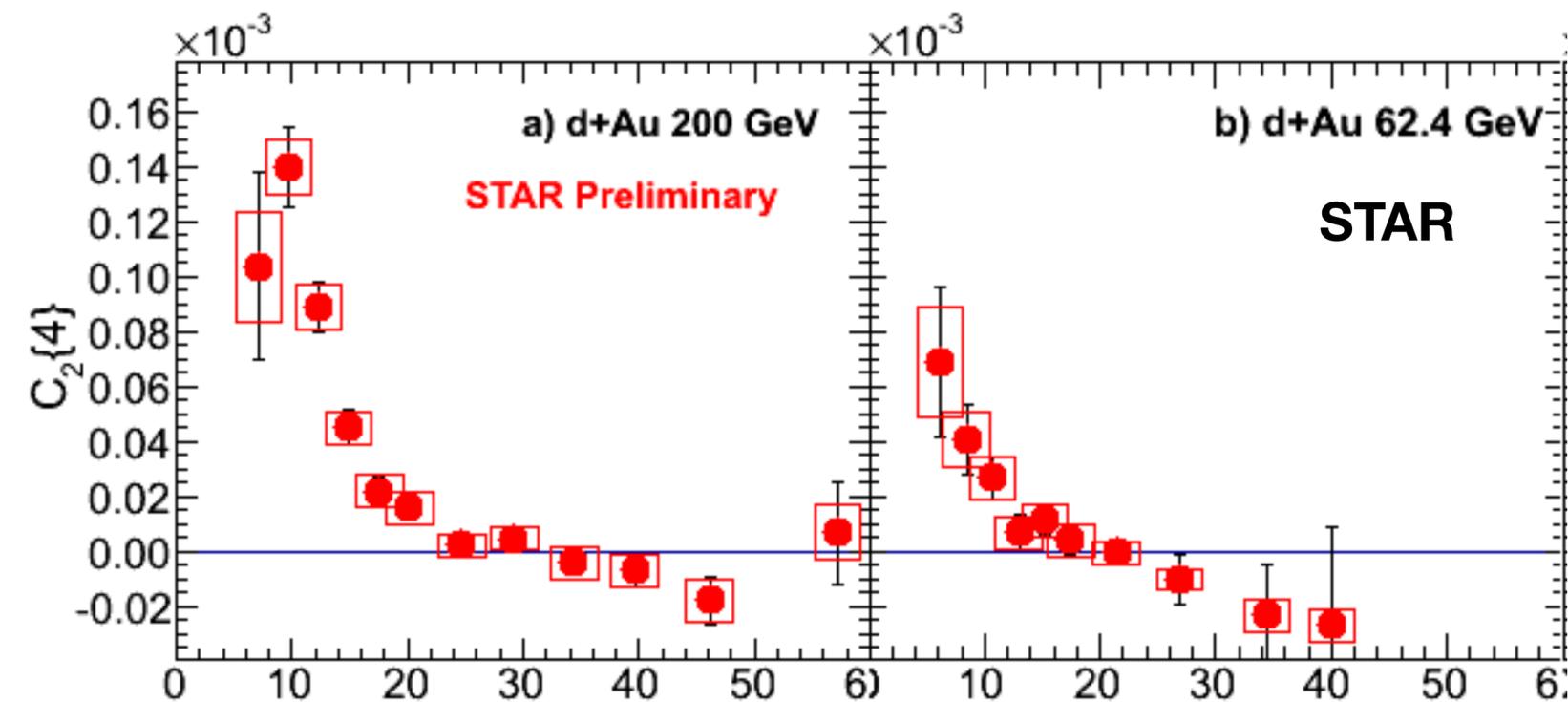
System shape scan



S. Morrow, QM18

v_n ordering, sensitive to initial geometry
Small QGP droplet?

4-particle cumulants

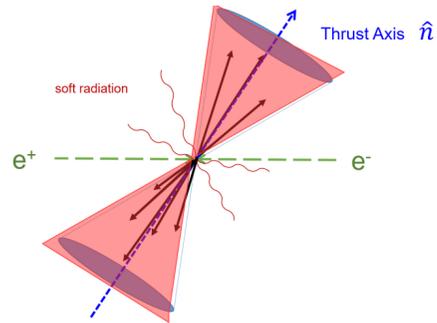


S. Huang, QM18

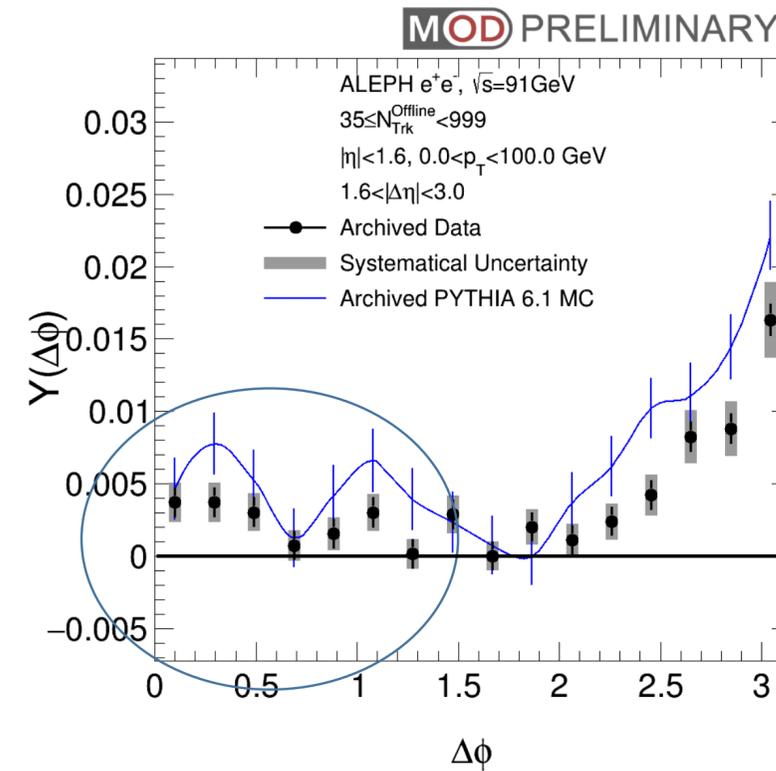
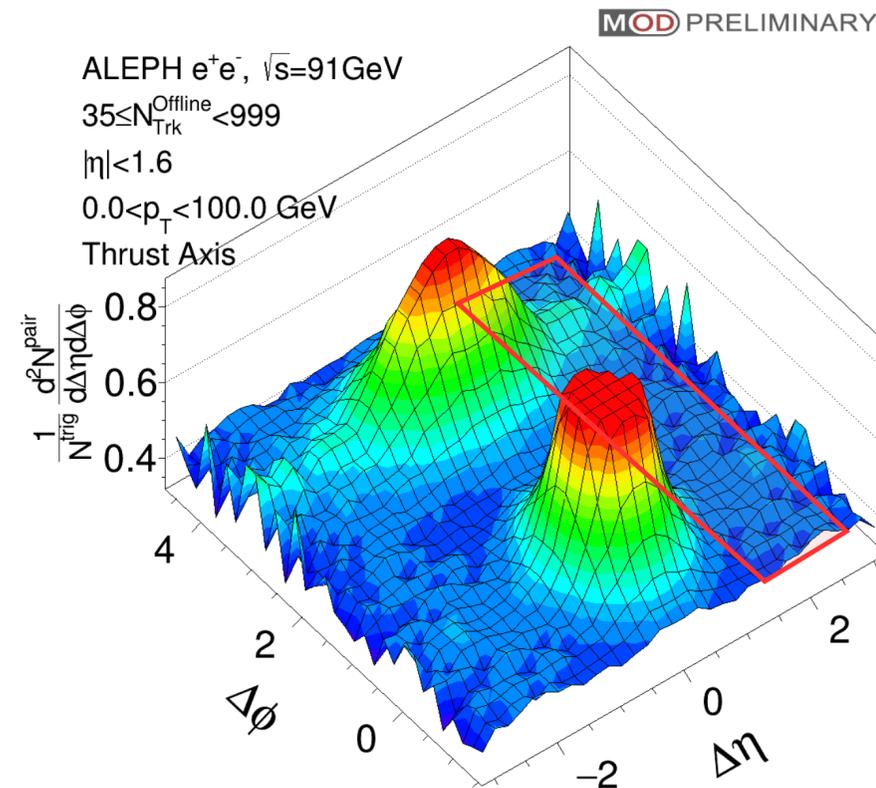
Negative $c_2\{4\}$

Even Smaller System

ep results:
S. Masciocchi, QM18



e^+e^- Y. Lee, QM18



Long-range correlation in e^+e^-

PYTHIA seems to be able to describe it

Nonflow Subtraction Challenge

STAR, PLB743 (2015) 333

- Nonflow dominant in small systems
- Different ways of nonflow subtraction

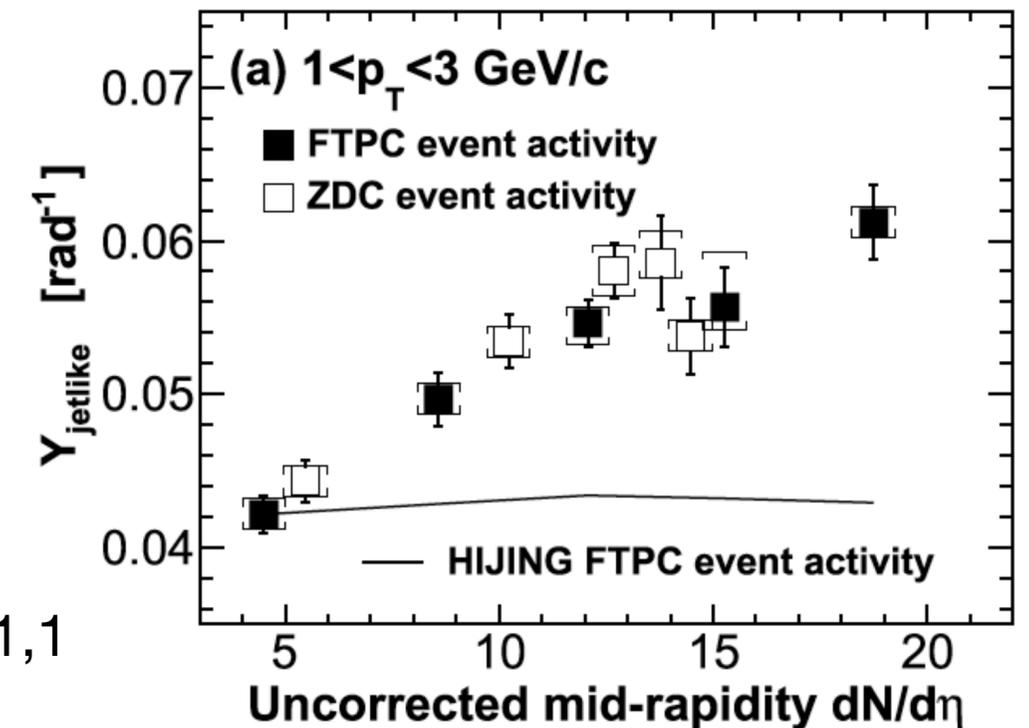
Multiplicity selection bias on jet

-> scaled jet subtraction

Templated fit: scale away-side jet effectively via $V_{1,1}$

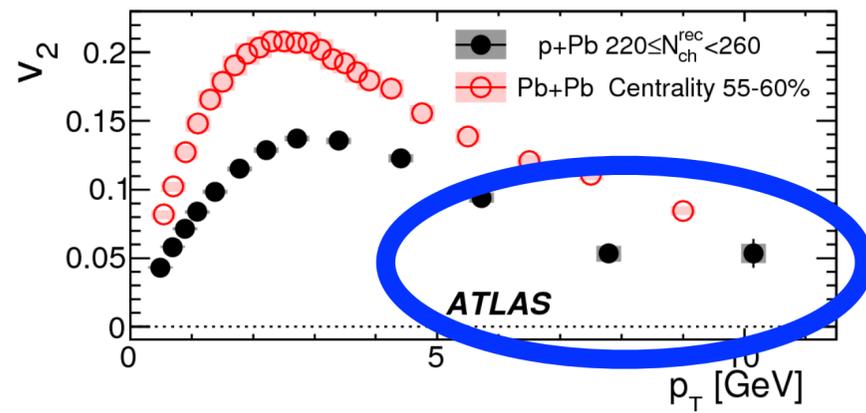
..

- Although large uncertainty in nonflow subtraction, it is clear there are anisotropies in small systems

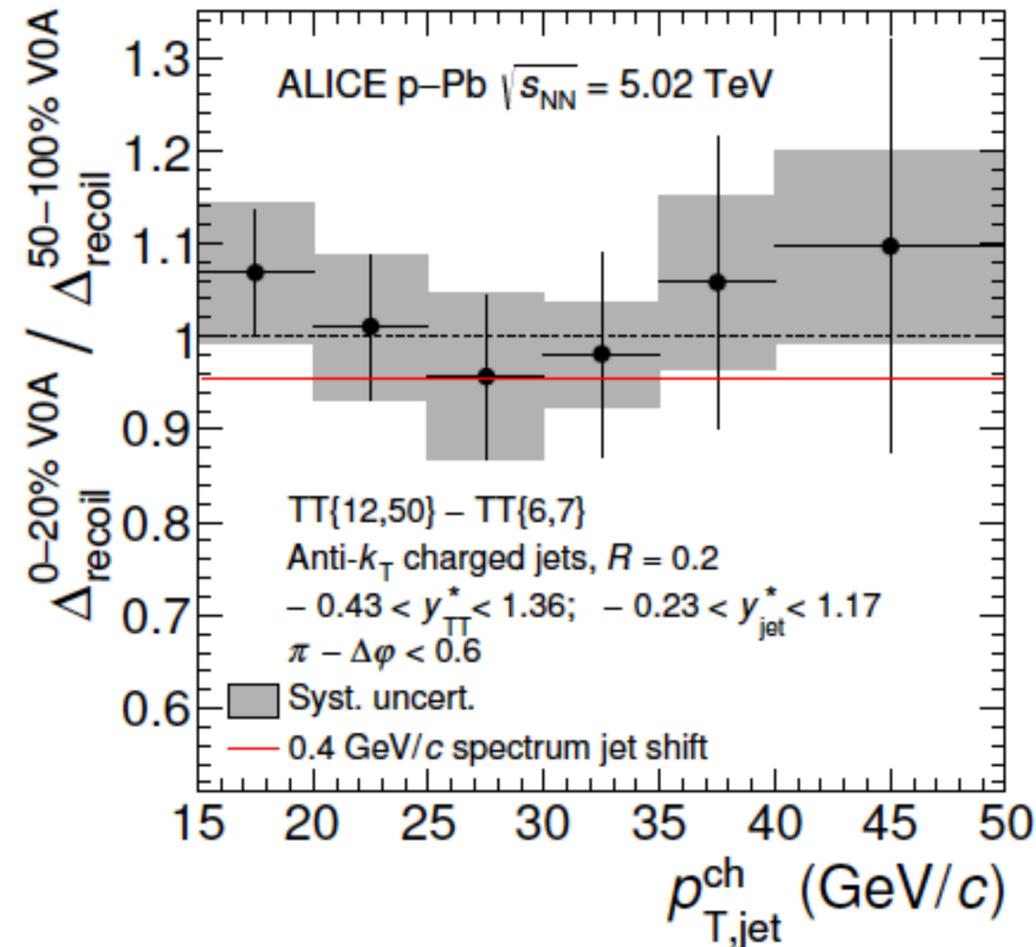


A Fly in the Ointment

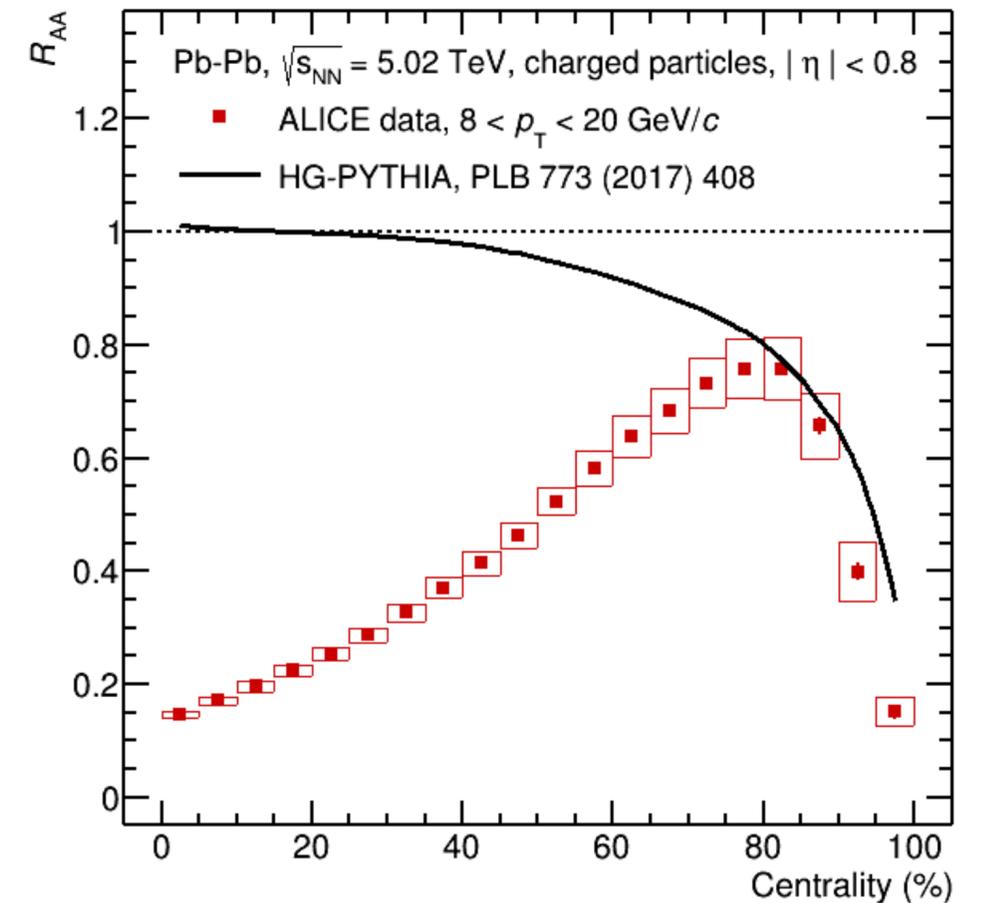
$v_2 \neq 0$, but No Jet Suppression in pPb & Peri. PbPb, $R_{pA} \sim 1$, no energy loss in small system



ATLAS, PRC90 (2014) 044906



ALICE, arXiv:1712.05603



ALICE, arXiv:1805.05212

Where does Collectivity Come from?

Next talk! M.Strickland

Hydro

High density system evolution

Smallest QGP droplet?

Initial **spatial** anisotropy, driven by **pressure gradient**

Low density

AMPT, “escape model”; Kinetic transport; ..

L. He, et al, PLB 753, 506

A. Kurkela, QM18

Initial **spatial** anisotropy

...

CGC

Initial **momentum** anisotropy

C. Bierlich, QM18

B. Blok, QM18

...

MPI + CR, ..

How can we distinguish the models?

Pressure Gradient

high density system

Pressure gradient

low density system

No pressure gradient

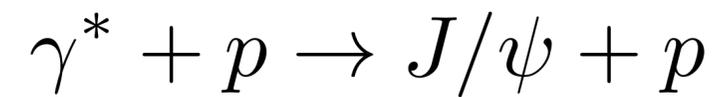
No radial flow?

PID spectra

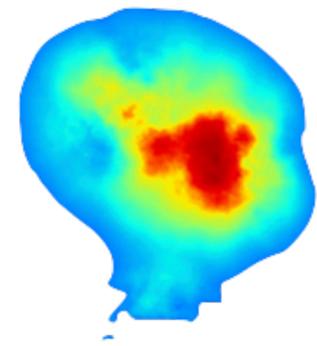
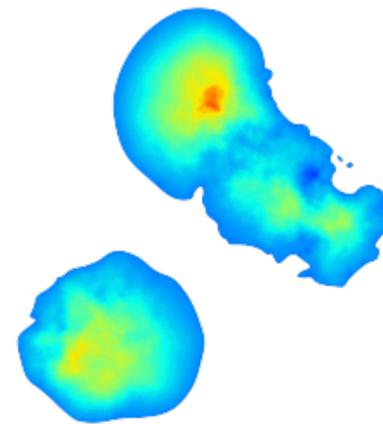
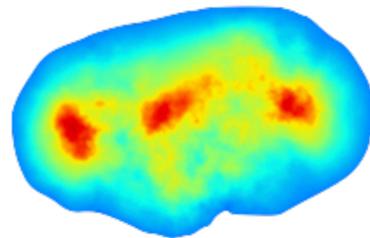
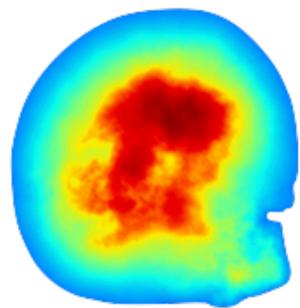
Probe Initial Geometry Fluctuation

Independent way to measure geometry fluctuations, other than v_n ?

Light diffraction with proton



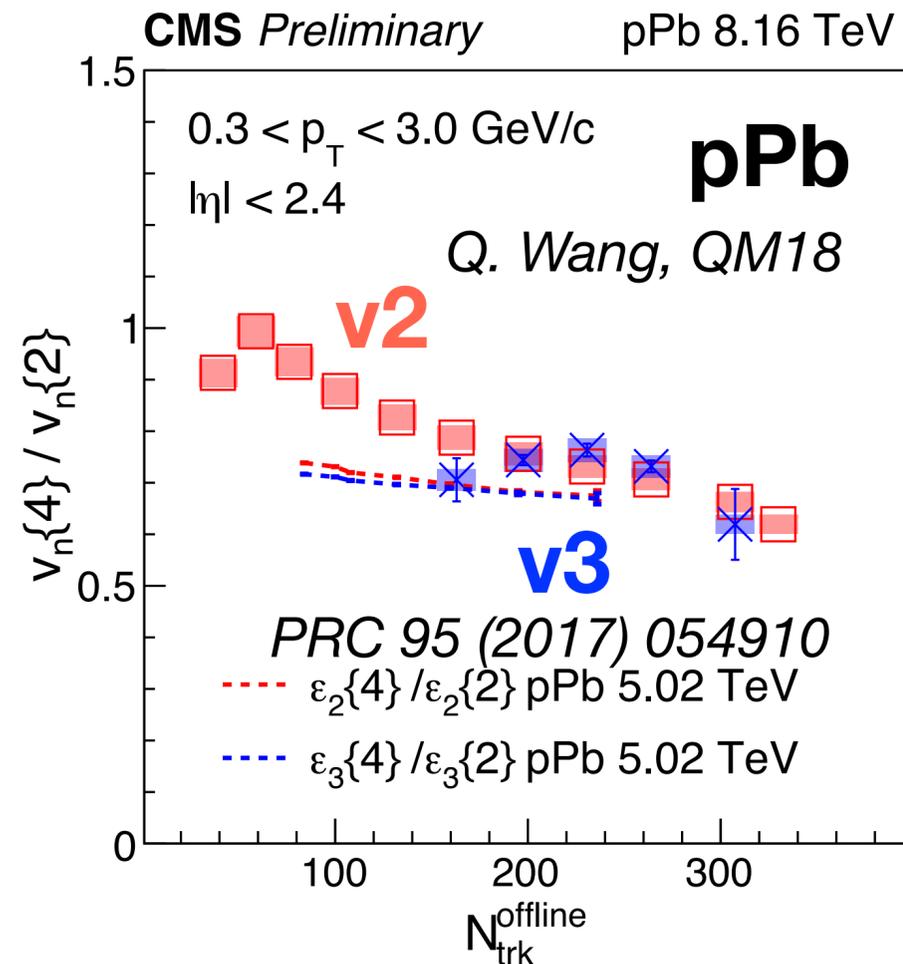
Mantysaari, Schenke



Initial Fluctuation

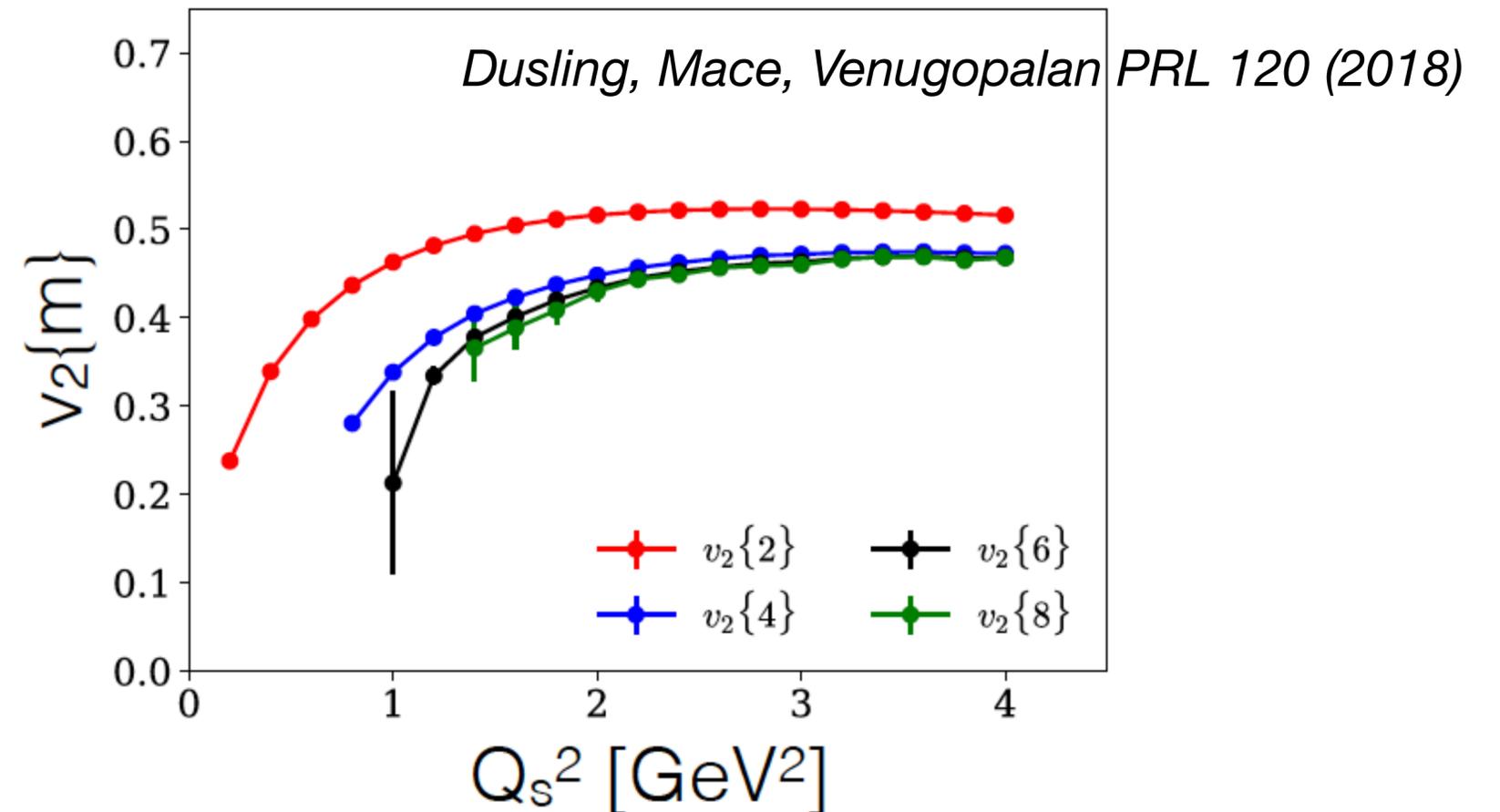
Initial **spatial** anisotropy

For hydro, v_n driven by geometry



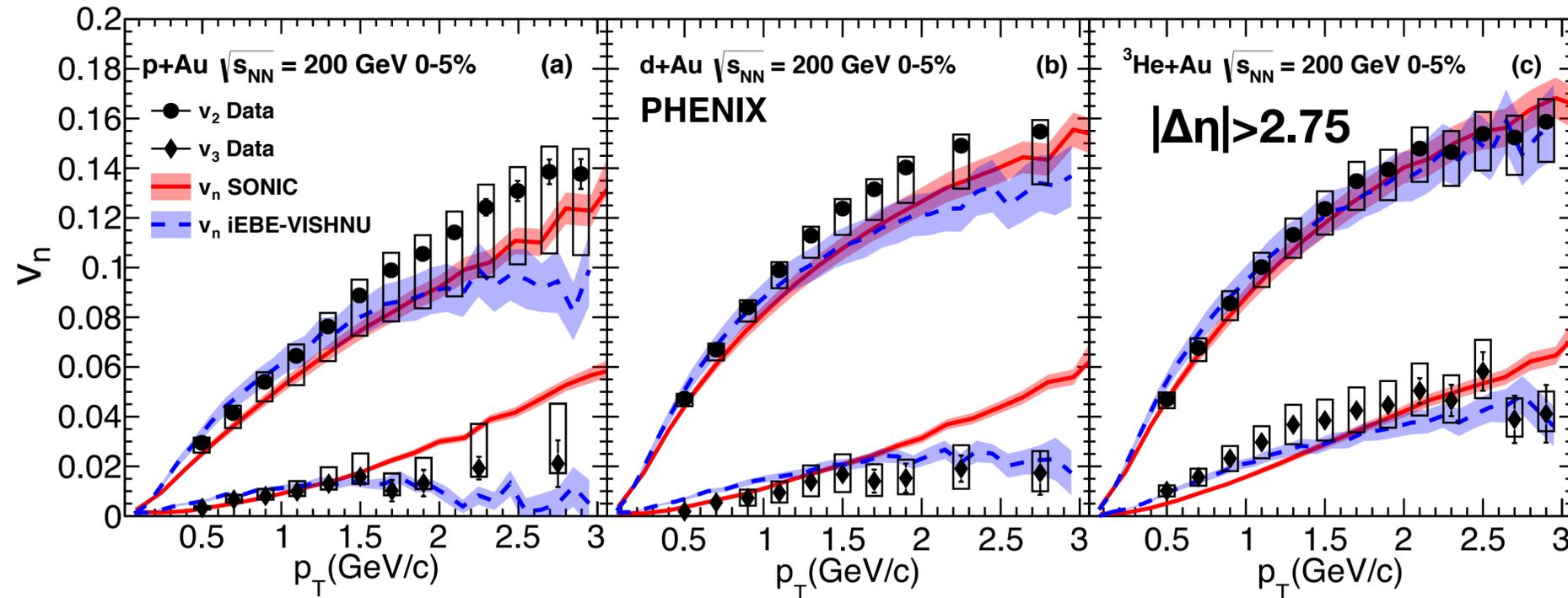
Initial **momentum** anisotropy

Coherently multiple scattering off localized domains of gluon shock wave



Does Eccentricity Make Difference?

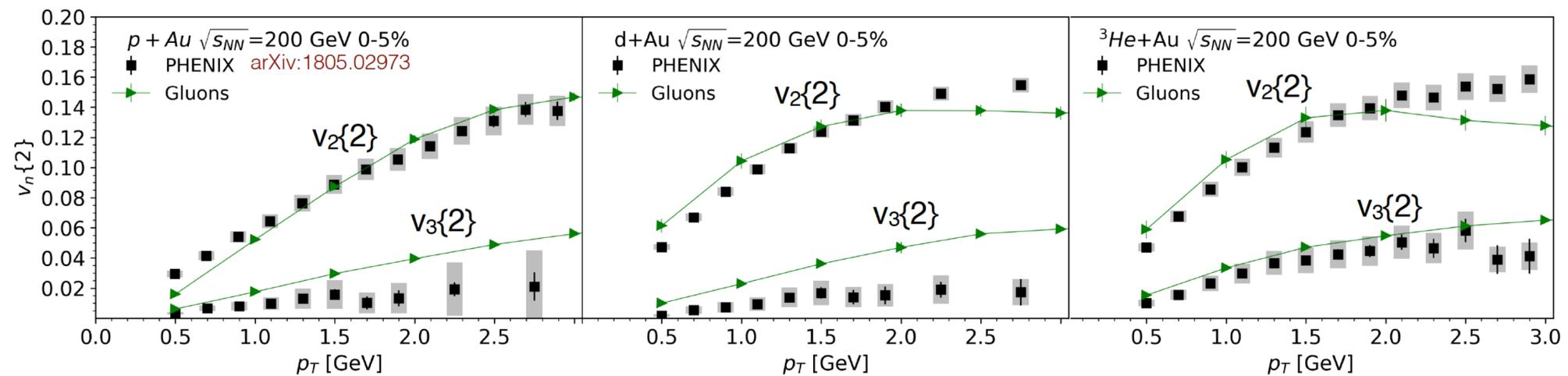
S. Morrow, QM18



**Geometry driven.
Smallest QGP droplet?**

Mace, Skokov, Tribedy, Venugopalan

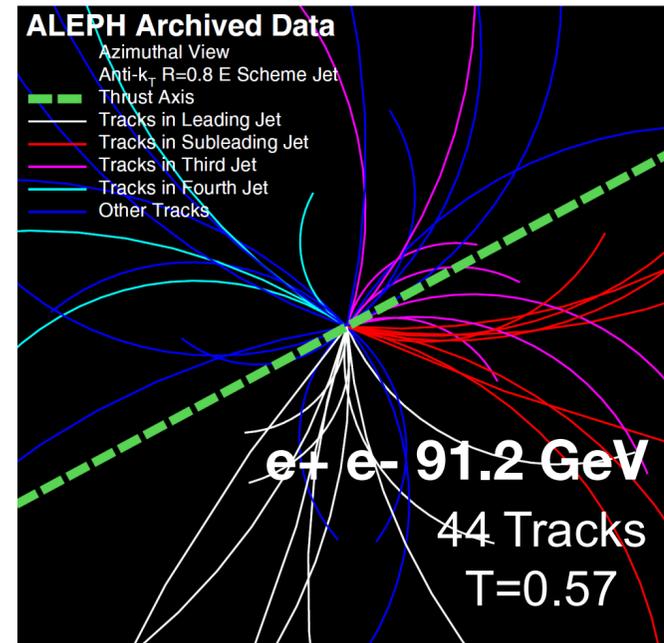
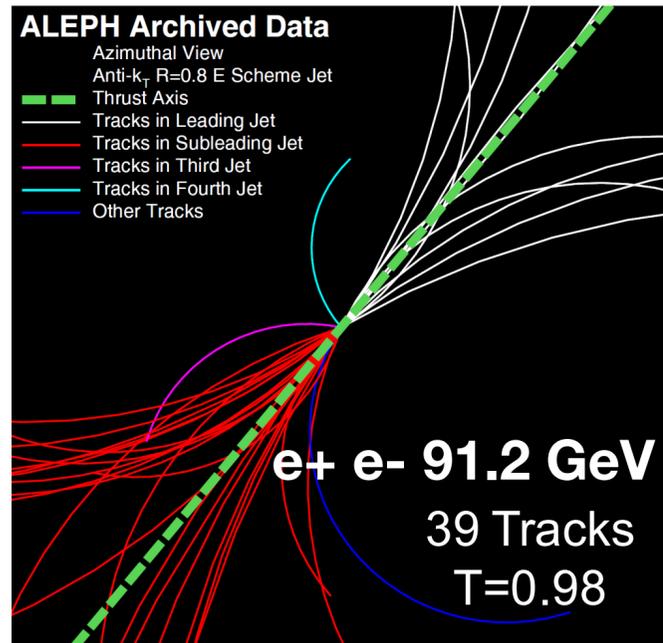
**Initial state gluon correlations
also “geometry driven”?
 $Q_s \rightarrow$ multiplicity dependence**



also see S. Huang, QM18

Event Shape Engineering

Y, Lee, QM18



$$T = \max_{\hat{n}} \frac{\sum_i |\hat{p}_i \cdot \hat{n}|}{\sum_i |\hat{p}_i|}$$

Similar multiplicity, different event shape

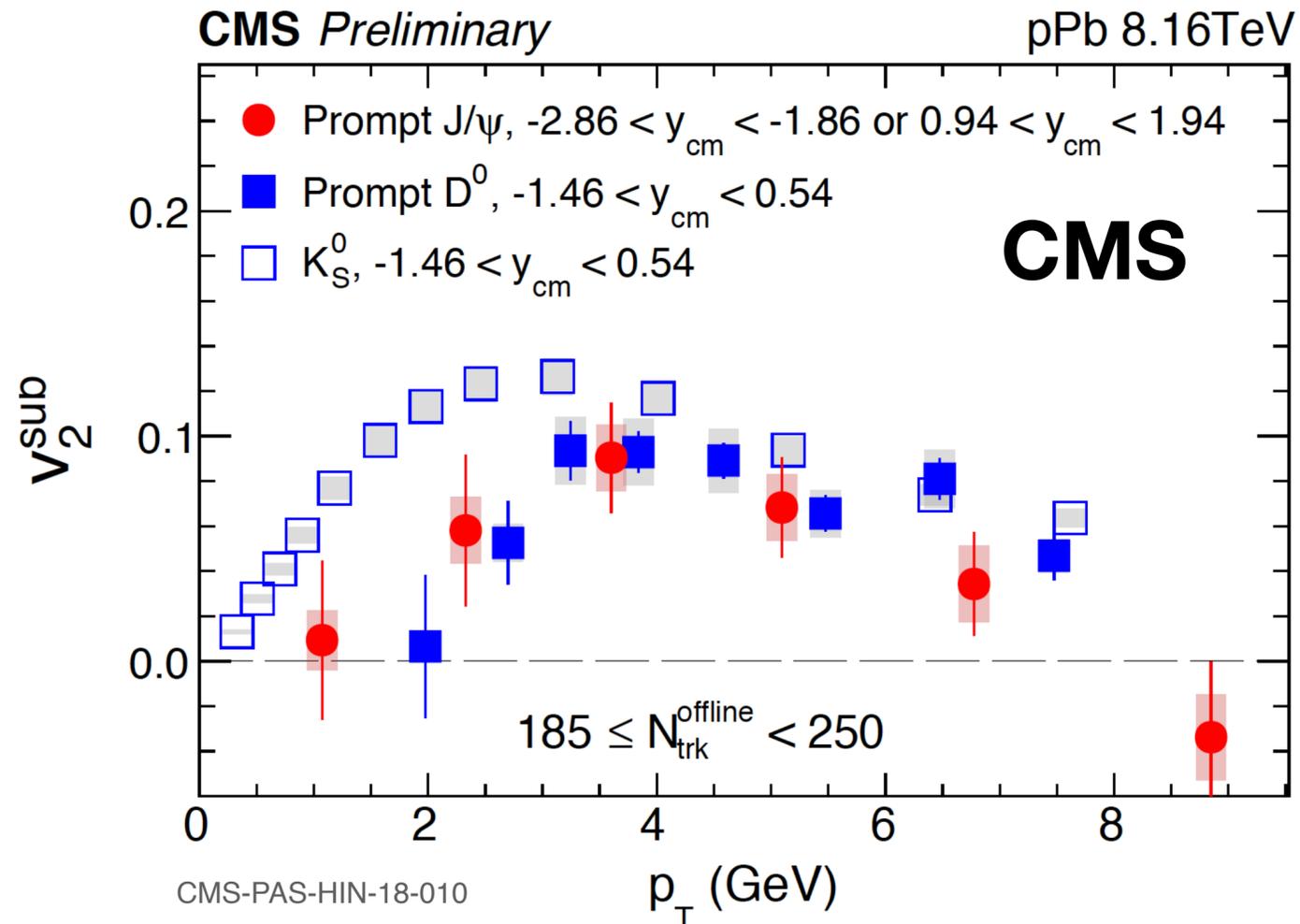
ESE selects geometry, different v_n in hydro

How about in CGC?

But ESE is selecting on final particle momenta

Must it be related to initial spatial geometry?

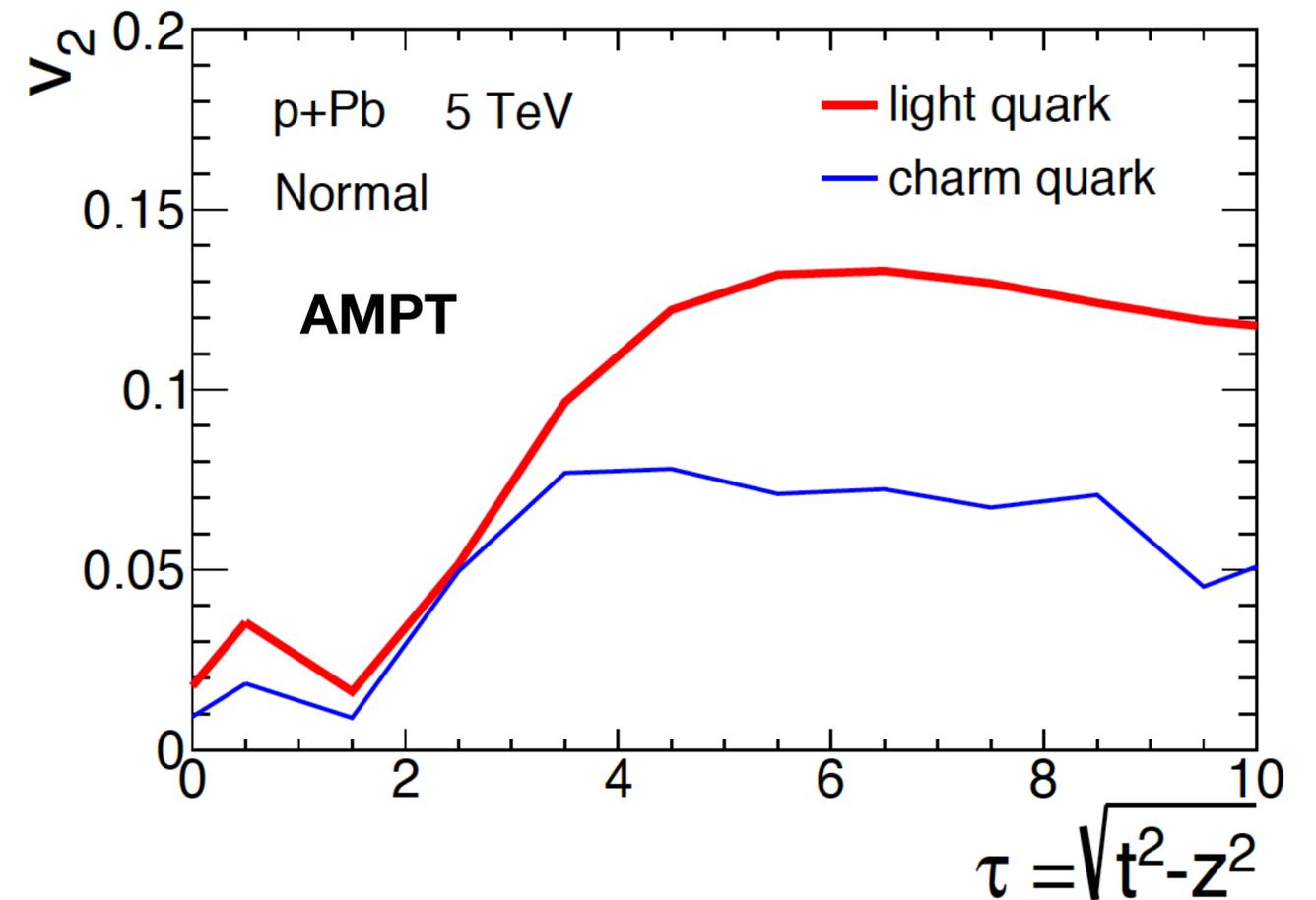
Non-zero Heavy Flavor v_2



W. Li, QM18

Heavy flavor flows almost as strongly as light flavors, in hydro.

Is can it be achieved in small systems?



H. Li et al 2017 J. Phys.: Conf. Ser. 779 012063

In AMPT, charm quark is more hydro than light quark less contribution from escape than light quark

Summary

Many interesting results in small systems. Evidence of collectivity in small systems:

- Heavy flavor flow
- Sub-event anisotropies with nonflow removed
- Massing ordering including multi-strangeness
- System shape scan
- ...

Interpretations still unclear

Open questions:

- Initial state effect: CGC?
- Final state effect: Hydro or low density transport?
- Or both initial+final state effects?